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ATOM OPTICS APPLICATIONS
23rd-28th May 1999

LES APPLICATIONS DE L'OPTIQUE ATOMIQUE
23 au 28 Mai 1999

Organizers - Organisateurs
Jacques VIGUE (Toulouse) - **John WEINER** (Toulouse) - **Dieter MESCHEDE** (Bonn)
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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 1999	Conference Proceedings

4. TITLE AND SUBTITLE

Atom Optics Applications, Conference, 23 – 28 May 1999, Les Houches, France

5. FUNDING NUMBERS

F61775-99-WF038

6. AUTHOR(S)

Conference Committee

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Universite Paul Sabatier
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Toulouse 31062
France

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES

EOARD
PSC 802 Box 14
FPO 09499-0200

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

CSP 99-5038

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

A

ABSTRACT (Maximum 200 words)

The Final Proceedings for Applications of Atom Optics, 23 May 1999 – 28 May 1999

This is an interdisciplinary conference. Topics will focus on applications of atom manipulation with light forces for the purpose of creating new nanostructures and new instrumentation. An important component of the workshop will be to compare light force techniques with competing technologies to assess the relative strengths and weaknesses of each. Atom manipulation will be considered in two broad categories: (1) direct-write deposition of atoms on surfaces for the purpose of making functional structures at the nanoscale. These structures include sources of electrons and photons and position-sensitive sensors and gravity detectors. The precision and sensitivity inherent in matter-wave interferometery holds the potential for new generations gyros and other navigational sensors.

14. SUBJECT TERMS

EOARD, Coatings, Fluids, Lubrication, Materials

15. NUMBER OF PAGES

32

16. PRICE CODE

N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19, SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

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2. Scientific committee – Le comité scientifique

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3. Acknowledgements – Remerciements

We wish to thank the following for their contribution for the success of this conference :

Nous souhaitons remercier les organismes cités ci-dessous pour leur contribution au succès de cette conférence :

- **CNRS** (département scientifique SPM, B.N.F., Service des ressources humaines de la Délégation régionale Midi-Pyrénées),
- **Ministère des Affaires Etrangères**, French Ministry of Foreign Affairs,
- **Ministère de la Défense Nationale**, DSP/Délégation Générale pour l'Armement,
- **EOARD** - European Office of Aerospace Research and Development, Air Force Office of Scientific Research and United States Air Force Research Laboratory.

4. Scope of the Workshop – Cadre scientifique

Atom optics deals with the interaction of light and matter, but the roles usually played by these two elements are reversed. Light fields can create forces with quite complex spatial structure which then act on atom beams as masks, lenses, or mirrors so as to project on a substrate a material image on a nanometer scale. Furthermore the wave properties of the atoms can be used to develop an atomic interferometry at the scale of the deBroglie wavelength. Such an atomic interferometry can lead to a new class of instrumentation (gyros, gravitational meters, etc.) with sensitivity and precision enhanced by several orders of magnitude. Application of laser cooling techniques to atom beams has improved their intensity, spatial definition, and narrowed their velocity dispersion.Such beams have already found application, and their use as atom sources for atom optical studies is very promising.

L'optique atomique fait partie du domaine de l'interaction lumière-matière mais les rôles habituellement joués par ces deux éléments sont inversés. En effet, des champs lumineux peuvent créer des forces avec une structure spatiale éventuellement très complexe ce qui permet d'agir sur un faisceau atomique comme des masques, des lentilles ou des miroirs et de projeter une image matérielle de ce faisceau, focalisée à l'échelle d'une dizaine de nanomètres. On peut de plus exploiter les propriétés ondulatoires des atomes afin de développer une interférométrie atomique à l'échelle de la longueur d'onde de de Broglie. Une telle interférométrie peut conduire à une nouvelle classe d'instrumentation (gyros, gravimètres, etc.) dont la sensibilité et la précision seront meilleures que ce qui est actuellement réalisable par plusieurs ordres de grandeurs. L'application des techniques du refroidissement laser aux faisceaux atomiques a permis d'améliorer fortement leur intensité et leur définition spatiale et de contrôler leur distribution de vitesse. Ces faisceaux ont déjà trouvé des applications et leur usage comme sources d'atomes pour les études de l'optique atomique est très prometteur.

5. The invited speakers – Les conférenciers invités

Mr	BERMAN	Paul	Professeur	University of Michigan
Mr	BLOCH	Immanuel	Doctorant	Max-Planck-Institut für Quantenoptik
Mr	BORDE	Christian	DR CNRS	CNRS
Mr	GROSS	Gerhard	Directeur Division Lithographie	Semiconductor MAnufacturing TECHnology (SEMATECH)
Mr	HINDS	Ed	Professeur	University of Sussex
Mme	LEE	Siu Au	Professeur	Colorado State University
Mr	MARECHAL	Etienne	Doctorant	UNIVERSITE PARIS 13
Mr	McCLELLAND	Jabez	Physicist	National Institute of Standards and Technology (NIST)
Mr	MESCHEDE	Dieter	Professeur	Bonn Universitaet
Mr	PFAU	Tilman	Professeur	Konstanz Universitaet
Mme	PRENTISS	Mara	Professeur	Harvard University
Mr	RIEDER	Karl Heinz	Professeur	Freie Universitaet Berlin
Mr	SCHMIEDMAYER	Jörg	Researcher	Leopold Franz Innsbruck Universitaet
Mr	VIGUE	Jacques	DR CNRS	CNRS Laboratoire CAR
Mr	WEINER	John	Professor	Laboratoire CAR
Mr	WESTBROOK	Chris	DR CNRS	CNRS
Mr	YABLONOVITCH	Eli	Professeur	UCLA Electrical Engineering Dept.
Mr	WEITZ	Martin	Professeur	Max-Planck-Institut für Quantenoptik

6. Scientific program – Programme scientifique

	Monday 24th may Lundi 24 mai	Tuesday 25th may Mardi 25 mai	Wenesday 26th may Mercredi 26 mai	Thursday 27th may Jeudi 27 mai	Friday 28th may Vendredi 28 mai
8.45 -10.00 Conference (1hr + 15 m discussions)	Gerhard Gross Sematech "Lithography Forever"	Jabez McClelland NIST "Direct deposition of nanostructures with light-force microlenses"	Etienne Maréchal Villetaneuse University "Applications of polarization atom interferometry to high-sensitivity gravimetry" / Martin Weitz Max Planck Institut of Quantum Optics "Multiple Beam Atom Interferometry"	Eli Yablonovitch UCLA "Photonic Crystals and their implementations"	John Weiner Paul Sabatier University "Nanoprobes activées par la lumière - applications en imagerie et lithographie" / Jacques Vigué Paul Sabatier University "Atom interferometry using light mask"
10.00 -10.20	Coffee break	Coffee break	Coffee break	Coffee break	Coffee break
10.30 - 11.45 Conference (1hr + 15 m discussions)	Christian Bordé Villetaneuse University "Introduction to atom interferometry"	Mara Prentiss Harvard University "Direct-write atom lithography using metastable atoms"	Jörg Schmiedmayer Innsbruck University "Atom interferometry applied to nanostructure fabrication"	Siu Au Lee Colorado State University "2D Structures in Ga and In"	End of session
12.00 - 16.00	Lunch + freetime	Lunch + freetime	Lunch + freetime	Lunch + freetime	Lunch + freetime
16.00 - 17.30 Informal meetings (round tables, workshop)	Immanuel Bloch Max Planck Institut ofQuantum Optics "Atom laser and coherence properties of BECs"	Poster session on "Light-force lithography"	Poster session on "Atomic interferometry"	Round tables on "Future applications of nanolithography"	
17.45 - 19.00 Conference (1hr + 15 m discussions)	Ed Hinds Sussex university "Atom manipulation using magnetic forces I"	Karl Heinz Rieder FU Berlin "Scanning probe microscopy manufactoring methods"	Paul Berman Michigan university "Atom interferometry using the Talbot effect"	Responsable of TMR, LETI "Proper (and improper) Relationship between university basic research and private industry"	
19.30 - 20.30	Dinner	Dinner		Dinner	
20.45 - 21.45 Informal meetings (round tables, workshop)	Chris Westbrook IOTA "Atom manipulation using magnetic forces II"	Dieter Meschede Bonn University "Light force nanolithography in Cesium" / Tilman Pfau Konstanz University "Light force nanolithography in Chromium"	Conference dinner	Round tables on "Future applications of atomic interferometry (Decelerated beams, Talbot effect)"	

7. List of participants - Liste des participants

Mr	BIZE	Sébastien	PhD student	CNRS
Mr	BERTRAM	Ralph	PhD student	Institut fur Angewandte Physik, Uni Bonn
Mr	BOSCH	Roel	Researcher	Technical University Eindhoven
Mr	BOUSTIMI	Mohamed	PhD student	Université de Paris Nord
Mr	BUCHNER	Matthias	Researcher	Laboratoire CAR
Mme	CHAMPENOIS	Caroline	PhD student	Laboratoire CAR
Mr	DAVIDSON	Nir	Researcher	Weizmann Intitute of Sceince
Mr	FILS	Jérôme	PhD student	LHA Université de Paris Sud
Mr	HARUTYUNYAN	Hayk	PhD student	Engineering Center of NAS Armenia
Mr	HAUBRICH	Dietmar	Post-Doc	Institut fur Angewandte Physik, Uni Bonn
Mr	ISHKHANYAN	Artur	Researcher	Engineering Center of NAS Armenia
Mr	JOZEFOWSKI	Leszek	Researcher	CNRS
Mme	KELLER	Claudia	PhD student	Universitaet Wien, Institut fuer Experimentalphysik
Mr	KUHN	Olivier	Post-Doc	Mikroelektronik Centret
Mr	LEINEN	Henry	PhD student	Institut fur Angewandte Physik, Uni Bonn
Mr	VAN LEEUWEN	Ton	Researcher	Eindhoven University of Technology
Mr	MERIMECHE	Habib	PhD student	Institut fur Angewandte Physik, Uni Bonn
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Mr	NAIRZ	Olaf	PhD student	Institute of Experimental Physics
Mr	OVCHINNIKOV	Yuri	Researcher	NIST
Mme	PRUVOST	Laurence	Researcher	CNRS Laboratoire Aimé cotton
Mr	SCHOLTEN	Robert	Professor	Melbourne University
Mr	SNADDEN	Michael	Researcher	University of Strathclyde
Mr	TURLAPOV	Andrey	Researcher	MIT - Research Laboratory of Electronics

8. Poster session on "Light-force lithography" – Session de posters sur "La lithographie par forces lumineuses"

- Fabrication of nanostructures by laser focusing of Fe atoms (**Roel BOSCH**)
- Precise measurements of the bichromatic force (**Harold METCALF**)
- Atom-lithography with a pulsed optical standing wave (**Dieter MESCHEDE**)
- Light-force lithography in chromium (**Tilman PFAU**)
- Periodic atomic structures fabricated in a time-domain interferometer (**Andrey TURLAPOV**)
- Transducer for in-situ monitoring of mass deposition with nanometer scale spatial resolution (**Olivier KHUN**)
- Adiabatic and coherent lenses for cold-atom lithography based on repulsive light force (**Nir DAVIDSON**)
- Natural magnetic mirrors for atom optics (**Dietmar HAUBRICH**)
- Preparation of an indium atomic beam for atom lithography (**Henry LEINEN**)
- Non-interferometric phase imaging of atoms (**Robert SCHOLTEN**)
- Light confining structures for organic material based optoelectronic devices (**Bruno MASENELLI**)
- New theoretical developments in high-contrast atomic focusing (**Jayson COHEN** and **Paul BERMAN**)
- The influence of magnetic sublevels coherence on the anomalous scattering of atoms in the field of a standing wave (**A.M. ISHKHANYAN, H.L. HARRUTYUNYAN**)
- High order Talbot images and nanostructures (**K.A.H. VAN LEEUWEN**)

« Fabrication of nanostructures by laser focusing of Fe atoms »

Roel BOSCH, Technical University Eindhoven - Den Dolech 2 - P.O. Box 513

We present an improved atom lithography method for the production of nanomagnetic wires and dots having well defined shape and separation. It is based on laser manipulated deposition of a supersonic beam of Fe atoms.

The nodes of a 372 nm standing light wave act as a perfect lens for an incoming monochromatic parallel atomic Fe beam. The feature size of the deposited structures is therefore first of all limited by the quality of the incoming beam, and secondly by spherical aberration.

A parallel beam is obtained by well known laser cooling techniques, but our improvement lies in the reduction of chromatic aberration by using a self-developed Fe evaporation source seeded with high pressure argon gas. The mixture will expand supersonically and due to adiabatic cooling it is in principle possible to obtain a beam with an axial velocity spread of less than 10%.

The problem of spherical aberration will be solved with beam masking: a transmission grating with 100 nm slit sizes upstream of the standing wave allows only atoms near the nodes to be deposited.

With the presented method we expect to reduce the structure sizes produced by conventional atom lithography methods and to break the 10 nm limit.

Abstract submitted to
ATOM OPTICS APPLICATIONS
Les Houches, France
23rd-28th May 1999

Precise Measurements of the Bichromatic Force*

Martin Williams, Matt Cashen, Felix Chi, and Harold Metcalf

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The limit on the magnitude of radiative forces of $\hbar k\gamma/2$ imposed by the spontaneous decay rate γ of the excited state can be overcome by coherent control of the momentum exchange between atoms and the light field. This can be implemented with light beams containing two frequencies in the form of rectification of the dipole force, but its velocity range is limited to $\sim \gamma/k$. Recently there has been a demonstration of beam slowing by the very strong bichromatic force whose velocity range is limited only by laser power[1]. We have made precise measurements of this bichromatic force by deflecting a thermal beam of Rb atoms. We used a standing wave of circularly polarized light whose components had carefully chosen relative phases, amplitudes, and frequency differences. Our results show its extremely large magnitude and velocity range, and also show that its velocity dependence near the edge of the range is suitable for atomic beam slowing and laser cooling. Our measurements have corroborated various models and calculations of this bichromatic force in great detail.

* Supported by ONR and ARO

1. J. Söding et. al, Phys. Rev. Lett. **78**, 1420 (1997)

Atom-lithography with a pulsed optical standing wave

M. Mützel, D. Haubrich, H. Merimeche, D. Meschede
Institut für Angewandte Physik,
Universität-Bonn, Germany

The production of periodic nanostructures by focussing an atomic beam in a cw standing wave has been subject to extensive theoretical and experimental studies during recent years. We examine the focussing of a Cs atomic beam in a pulsed optical standing wave. Theoretically we describe the interaction of the Cs atoms with the light field with the optical Bloch equations. The solution of these equations leads to the theoretical force on the atoms and it turns out that the trajectories of the atoms in the pulsed case are similar to the cw- case.

In our experiment we use a modelocked Ti:Sapphire laser with pulslengths between 30 and 100ps and a repetition rate of 80 MHz to investigate the interaction of the atoms with the light field. We will demonstrate our latest results.

Light force lithography in chromium

T. Pfau*, B. Brezger, Th. Schulze, J. Mlynek; University of Konstanz, 78457 Konstanz, Germany

In atom lithography, neutral atoms are focused by laser light to form a periodic pattern on a substrate. We have realized a varitety of two-dimensional structures of chromium on a silicon substrate by employing a polarization gradient light mask with uniform intensity [1] as well as intensity gradient. The generated structures exhibit periods below 100nm. The results are explained by a theoretical model which takes into account the magnetic substructure of the atomic transition employed and the influence of a static magnetic field. Future atomlithography experiments will make use of the selectivity of the atom light interaction. By structuring a dopand in a homogeneously growing matrix a material can be fabricated that provides a change of its optical properties on the scale of the optical wavelength. This may find applications in the field of photonic crystals.

[1] B. Brezger, Th. Schulze, P.O. Schmidt, R. Mertens, T. Pfau, and J. Mlynek; Europhys. Lett. in press.

* current adress: Department of Physics and Research Laboratory of Electronics; Massachusetts Institute of Technology, Cambridge, MA 02139, USA

Periodic atomic structures fabricated in a time-domain interferometer

Andrey Turlapov, D. V. Strekalov, A. Kumarakrishnan[1], S. B. Cahn[2], and Tycho Sleator

New York University, Department of Physics,
4 Washington Place, New York, NY 10003

We have developed an experimental method for fabricating periodic structures in a gas of cold atoms or in an atomic beam using optical standing waves of wavelength λ. The period of these structures is an integral fraction of $\lambda/2$. The ability to produce sub-$\lambda/2$ structures makes our technique applicable to atomic beam lithography. As a first step, we did an experiment in a cloud of ~100 μK ^{85}Rb atoms and observed structures of period $\lambda/2$ and $\lambda/4$. In this experiment, three subsequent short standing-wave pulses, detuned from resonance with ^{85}Rb, act as phase gratings for atomic matter waves. Shortly after the first pulse, a modulation in the atomic density with period $\lambda/2$ appears, containing spatial harmonics of period $\lambda/2N$ (N is an integer). The structure rapidly vanishes due to the atomic thermal motion. Atomic wavefunctions, however, preserve phase memory about this modulation on a long time scale. To produce structures of period smaller than $\lambda/2$, one must eliminate the lower spatial harmonics. This can be done by applying the second standing wave pulse long after the initial modulation has washed out. The pulse selects higher spatial harmonics and results in a temporal sequence of atomic density gratings of periods $\lambda/2N$, where gratings with different values of N appear at different times after the second pulse. In particular, the reappearance of the modulation with period $\lambda/2$ is referred to as an "echo". The third pulse (and a subsequent traveling wave pulse) are used to detect these gratings in real time. This sequence of three standing-wave pulses results in new types of "echoes".

[1]Presently at Massachusetts Institute of Technology, Research Laboratory of Electronics, 77 Massachusetts Avenue, Cambridge, MA 02139

[2]Presently at Yale University, Physics Department, 217 Prospect Street, New Haven, CT 06520

spatial resolution

Oliver Kuhn[1], Zachary Davis[1], Gabriel Abadal[1,2], Anja Boisen[1], Ole Hansen[1], Francois Grey[1]
[1]Mikroelektronik Centret, Technical University of Denmark, Bldg, 345east, 2800 Lyngby, Denmark
[2]Departament d'Enginyeria Electrònica, Universitat Autònoma de Barcelona. 08193-Bellaterra, Spain

In the recent years more and more fabrication techniques emerged that allow for depositing materials organised in nanometer scale patterns. Such techniques often suffer from the lack of in-situ deposition monitoring that can cope with the high demands on spatial resolution and mass deposition sensitivity. Monitoring for example the deposition of a 10nm wide and 10µm long chromium line at a rate of 27 Å/s requires a minimum mass deposition rate sensitivity of the order of 10^{-17} kg/s, while state of the art thin film deposition monitors are specified to a mass deposition rate sensitivity of 10^{-14} kg/s [1].

We report on the development of a resonator type transducer with lateral dimensions down to 100nm, with an active area of $1\mu m^2$, and with a thickness of the order of 1µm. The measurement principle is based on detecting the shift in resonance frequency of a micro-mechanical oscillator as its oscillating mass increases during material depositon. Theoretical estimates for cantilever type resonators of these dimensions indicate that a minimum detectable mass change of 10^{-24} kg should be achievable, thus exceeding the above mentioned specification requirements by several orders of magnitude [2]. From these considerations it becomes clear that in a suitable transducer the oscillator part will have to be scaled down to submicron dimensions.

First fabrication results are presented in figures 1 and 2. The devices are fabricated from Si-SiO_2-Si layer structures by means of reactive ion etching (RIE) and wet-etch oxide removal in a buffered solution of hydrofluoric acid (BHF). The RIE mask consists of a two-layer structure of modified aluminium on top of SiO_2. Patterns are defined using direct laser and AFM writing processes. Both negative and positive processes are available and allow for a large freedom in the pattern layout [3]. For laser written features, lateral resolution down to 500nm can be achieved (Fig. 1). Using complementary AFM-writing for defining the RIE-mask pattern, the critical feature sizes can be scaled down to 100nm [3]. Fig. 2 shows an oscillator consisting of a 15µm long, 200nm wide and 1.6µm high suspended bridge structure. The oscillation of the bridge is driven electrostatically in the transverse direction by a counter electrode placed next to the bridge.

References

[1] Leybold Inficon Inc., datasheet on "Thin film deposition controllers and monitors"
[2] Zachary Davis, report on "Nanocantilever Array for Mass detection", Mikroelektronik Centret 1998
[3] A. Boisen, K. Birkelund, O. Hansen and F. Grey, J. Vac. Sci. Technol. B 9, 2977 (1998)

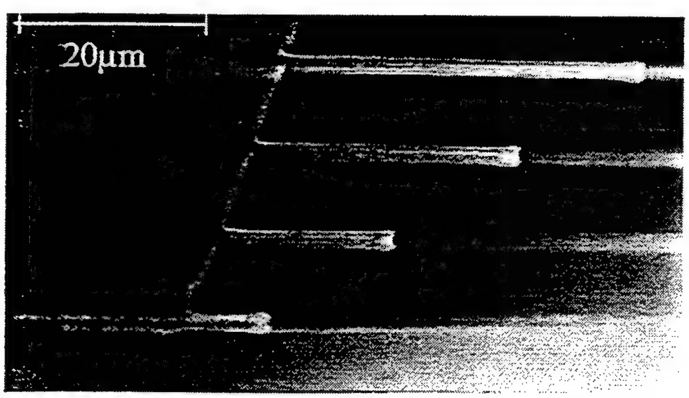

Fig. 1. SEM picture of an array of free standing cantilevers defined by laser writing. The cantilevers are about 500nm wide, and 1µm high.

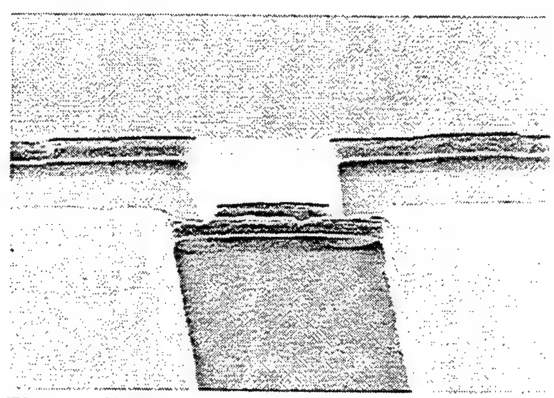

Fig. 2. SEM picture of a bridge resonator with square driver electrode defined by combined laser and AFM writing. The bridge shown here is 15 µm long. 200 nm wide, and 1.6 µm thick.

Adiabatic and coherent lenses for cold-atom lithography based on repulsive light forces.

Lev Khaykovich and Nir Davidson
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Weizmann Institute of Science, Rehovot 76100, Israel

Atomic lenses that are based on light forces have been used to focus atoms to ~50 nm dimensions and thus open the possibility for sub-micron atomic lithography [1]. Replacing the
thermal atomic beam with a cold atomic source reduces several of the main aberrations of the atomic lenses such as transverse-velocity and chromatic aberrations, and also results in a substantially longer interaction time between the atoms and light forces. In this regime, the main remaining aberrations are spherical aberrations and heating of the atoms by fluctuations in the light forces. Repulsive light forces tend to push atoms towards dark regions and thus to minimize their interaction with the light field [2]. We show that by resorting to such repulsive light sources, cold atoms can be compressed adiabatically by more than an order of magnitude in a blue-detuned standing wave configuration. An analytical model that describes the lens aberration in this regime enables global optimization of the lens properties. These parameters, as well as the compression ratios are found to be in agreement with the exact results of our Monte-Carlo simulations. Finally, we show that by combining adiabatic compression with coherent focusing (where the atoms complete exactly a quarter oscillation period) a further improvement of the compression ratio is obtained. In this configuration, the adiabatic compression acts as a preparation stage that brings the atoms closer to the potential minima, where its spherical aberrations are small.

[1] J. J. McClelland et. al., Science 262, 877 (1993).
[2] R. Ozeri, L. Khaykovich, and N. Davidson, Phys. Rev.
A 59, R1750. (1999)

Natural magnetic mirrors for atom optics

Dietmar Haubrich, Frank Lison, and Dieter Meschede
Institute for Applied Physics, University of Bonn

Several types of magnetic mirrors for atom optical applications have been designed and investigated during the last few years. The crucial issues for atom mirrors are the flatness of the equipotential surfaces and the maximum potential strength at the surface of the mirror.

We have investigated two different types of 'natural' mirrors with an inherent periodic magnetization due to the natural magnetic domain structure of the material. A Cobalt single crystal and an unmagnetized block of NdFeB material both possess a highly anisotropic structure which prevents the formation of closure domains at the surface. This leads to a rapidly decaying strayfield with a magnitude on the order of 1 Tesla.

We have characterized the surface using optical, AFM and MFM techniques. In the case of Cobalt we find a quite regular domain structure with domain sizes around 30 μm. The NdFeB material exhibits smaller domain structures in the range of a few microns. With a slow cesium atomic beam we have investigated the reflectivity and imaging properties of both mirrors.

Preparation of an Indium Atomic Beam for Atom lithography

H. Leinen, D. Gläßner, J. Clevorn, D. Haubrich, D. Meschede
Institut für Angewandte Physik,
Universität-Bonn, Germany

Atom lithography allows direct deposition of 2-dimensional, periodic structures. These structures can be realized by application of optical standing-wave fields, thereby making use of light-forces. This has already been demonstrated by several groups using different materials. Due to its element selectivity, it should be possible to extend this technique to create 3-dimensional structures, if a second atomic beam is used. An interesting application is the creation of photonic crystals where a periodic variation of the refractive index leads to photonic bandgaps.

In order to increase the contrast of the resulting structures, the atomic beam has to be transversally collimated. The application of spontaneous light-forces which leads to significant divergence reduction requires a closed atomic transition. In the case of Indium, the preparation of this transition can be achieved by optical pumping from the ground-state.

With this contribution we will report about our progress in the creation and preparation of an Indium atomic beam. The experiment requires laser sources at 410 nm and 325 nm. These laser sources are realized by frequency doubling of red diode lasers. We will further present our first spectroscopic results using one of the first blue laserdiodes commercially available.

Non-interferometric phase imaging of atoms

M.R. Walkiewicz, C.J. Vale, D.Paganin, K.A. Nugent and R.E.Scholten

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The phase of an electromagnetic or matter wave is not directly observable in the same manner as the wave amplitude, and it is generally assumed that it must be measured using interferometry. Such phase information is important to a broad variety of applications, for example experiments in fundamental quantum mechanics, measurements of gravity and gravitational gradients, of rotation, atomic interactions and so on [1]. Unfortunately, building interferometers for matter waves, in particular for neutral atoms, can be surprisingly difficult. Recently, a new understanding of phase has been developed at the University of Melbourne [2–5], showing that phase can be measured without interferometry. We extend this non-interferometric phase recovery method to matter waves, and show that it provides information which might otherwise be recovered using interferometry.

Phase is linked to the direction of propagation of energy, and this can be used to extract phase from measurements of intensity, as described in detail in [2–5]. The concept is essentially based on Huygen's principle, that the field propagates perpendicular to the wavefront. Thus measuring the direction of propagation is equivalent to measuring the wavefront. The two are linked through the transport of intensity equation:

$$-k\frac{\partial I(\vec{r}_\perp,0)}{\partial z}=\nabla_\perp \bullet \left(I(\vec{r}_\perp,0)\nabla_\perp\phi(\vec{r}_\perp,0)\right)$$

where is the k is the wavenumber, $\partial I/\partial z$ is the derivative of I with respect to the optical axis, and ϕ is the phase. $\nabla_\perp$ is the two-dimensional gradient operator acting in a plane perpendicular to the optical axis and $\vec{r}_\perp$ is the position vector in that plane. It has been shown that, in the absence of intensity zeroes, this equation has a unique solution for the phase [2]. Furthermore, the definition of phase used in the above equation may be extended to partially coherent fields for which phase is not conventionally defined. The resulting «phase» responds to potentials in an identical way and reduces to conventional phase in the coherent limit. The intensity derivative is found by measuring the intensity distribution at two planes along the optical axis, and provides two-dimensional and quantitative phase images without the modulo-2π problem of interferometric phase measurements.

We present measurements of the phase change in an atomic beam induced by the effects of near-resonant laser light and discuss future prospects.

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LIGHT CONFINING STRUCTURES FOR ORGANIC MATERIAL BASED OPTOELECTRONIC DEVICES.

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Light-emitting planar microcavities were first constructed from the organic molecular material tris (8-hydroxy-quinoline) aluminum (Alq_3), placed at different locations between two distributed Bragg reflectors. The reflectors were made from the dielectric couple TiO_2/SiO_2. The resulting cavities were resonant at approximately 515 nm and had a full width at half maximum of about 13 nm.

The modifications of spontaneous emission at the resonant wavelength in the forward direction according to the location of the emissive layer in the cavity, predicted by Purcell's law, have been investigated by photoluminescence experiments. Enhancements ranging from 3 to 20 have been observed, depending on whether the Alq_3 layer is located at a node or at a maximum of the electric field, respectively. Modifications of the radiation pattern have been measured. These results have been confronted with a complete simulation.

Secondly, the knowledge of planar microcavities has been extended to the modelization and fabrication of microcavities confining light along two dimensions. The light confinement along the normal axis is provided by a dielectric Bragg reflector and an aluminum reflector, while the lateral confinement is obtained by aluminum reflectors. This results in a rectangular section microcavity, whose dimensions are λ (λ being 545 nm) along the normal axis, and a few λ (1or 2 µm) along the lateral axis. The effects of lateral confinement on angular emission pattern and leaky (waveguided) modes is currently under investigation by photo- and electro-luminescence.

Results coming from one-dimension and two-dimensions confining structures will be presented and confronted to theoretical predictions.

New Theoretical Developments in High-Contrast Atomic Focusing

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Atom focusing using laser fields with spatially varying intensities to focus atomic beams has attracted a large research effort over the past few years since the nonlinear atom-field interaction can lead to atomic density features much smaller than the wave length of light used to create them. The hope is to develop a robust system for writing and controlling nanoscale features on a substrate. We have developed and now present theoretical, quantum techniques to understand, control, and predict atom focusing in the thin lens (Raman-Nath regime) of the atom-laser interaction. The atoms come to a focus in the Fresnel diffraction region after passing through the laser field. These techniques can be applied with a high degree of accuracy to periodic, quasiperiodic, and non-periodic laser intensity patterns. We have exploited an exact Fourier technique to analyze atomic density patterns after they interact with periodic (standing wave) fields in the most interesting regime for high-contrast focusing, namely far-detuned fields and optically pumped atoms. In this regime the Fourier coefficients are known analytically. In general, the Fourier method automatically accounts for spherical aberration and facilitates an average over the transverse and longitudinal velocity distributions of the atomic beam. We have analyzed the standing wave lens for two-level atoms with the Fourier method to find all of the precise focal characteristics for various atomic velocity distributions and as a function of the effective atom-field pulse area. These lens characteristics include the focal distance, focal spot size, depth of focus, focal density profile, and background density. Our results allow for a straightforward physical interpretation of the atomic properties and their degradation as a result of chromatic aberration and beam divergence (Doppler dephasing).

We have also developed a theory for atoms interacting with new laser field configurations that eliminate the lower-order spatial harmonics of the field in the atomic wave function and create periodic atomic densities having periods of λ/n, where λ is the light wavelength and n is an integer greater than 2. For example, counterpropagating fields, where only one of the traveling waves is amplitude modulated in time, produce a lens with a $\lambda/4$ periodicity for two-level atoms. We have analyzed the quantitative focal characteristics of these smaller period lenses with the Fourier method.

In addition, we have developed an analytical, Fresnel diffraction theory of atom focusing based on the quantum free particle propagator that accounts for spherical aberration beyond the parabolic lens approximation. The asymptotic limit of our theory leads to universal scaling laws for the lens properties and density profiles as a function the pulse area in the large pulse area limit. This limit is the most relevant for creating high-contrast structures by either depositing atoms directly or using the atoms as a tool for lithography in metal and semiconductor materials. The diffraction theory can be applied to arbitrary laser intensity structures in space, including the often used standing wave, providing predictive control of the atom focusing process for a given field configuration. For example, we present quantitative results describing a type of conical mirror for laser beams that forms a single, localized intensity spot, creating a pen (single potential well) for writing atoms on a surface. We also show how the diffraction theory can be applied to dressed atom-standing wave field interactions, where the exact Fourier coefficients are not known analytically, but a Taylor expansion of the light-shift potential around the intensity maxima and minima can be made.

The in‡uence of magnetic sublevels coherency on the anomalous scattering of atoms in the ...eld of a standing wave.

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One of the fundamental phenomena in the problem of the interaction of atoms with a resonant standing-wave ...eld, is the coherent multiphoton scattering (di¤raction) of atoms(A. Zh. Muradyan Izvestia AN Arm:SSR; Fizika 10, 1975, p. 361).

Recently an anomalous (asymmetric and having an oscillatory frequency dependence) di¤raction of atomic beam in a standing wave pulses ...eld was observed(V.A.Grinchuk et al. Pisma Zh: Eksp: Teor: Fiz: 57, 1993, p 534). This type of scattering may be used for regulated de‡ection of the total atomic beam on large angles. The theoretical investigations show that the anomalous de‡ection, in all probabilities, is conditioned by the coherency between the ground and excited energy levels before the interaction with the standing wave(A. M. Ishkhanyan Laser Physics 7, no. 6, 1997, p1225).

This coherency between the atomic levels is induced by the preliminary interaction with a laser traveling wave, before the standing-wave formation. The model developed at the present is in the limits of scalar theory.

However, for real atoms, the preliminary coherency may appear also between the sublevels of the same energy and, consequently, it is necessary to clear up the in‡uence of this coherency on the process of anomalous scattering in the standing ...eld. To include this coherency into the atom-...eld interaction theory, an elliptically polarized ...eld must be chosen. Here we consider a simple optical transition $j_g = 1 \,!\, j_e = 0$.

It is clear from the obtained calculations, that the sublevels and polarization only e¤ect on the e¤ectivity of the total scattering process. And in di¤erence to the coherency between ground and excited states, the coherency between sublevels of the same energy level don't result in an asymmetry in the scattering.

High order Talbot images and nanostructures

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It has been demonstrated by several groups that focusing of atoms in optical standing waves can be used to produce periodic structures with feature sizes in the nanometer region, either through direct deposition from an atomic beam [1], or through exposing a resist layer on a substrate with metastable rare gas atoms and subsequent processing [2]. Feature sizes of 38 nm at spacings of 213 nm have been reported.

The application of near field imaging in atom optics to the production of regular nanostructures with a smaller period has been suggested, e.g., by Janicke and Wilkens [3]. In the near field diffraction pattern of atoms passing through a regular structure (e.g., a transmission grating or an optical standing wave), images with a regular structure with a period equal to an integer fraction of the original period can arise. These so-called fractional Talbot images have been observed by Nowak et al. [4] using metastable helium atoms passing through a transmission grating.

In principle, the combination of focusing and high-order fractional Talbot imaging should allow the production of structures with very small feature sizes as well as a small period. However, the aberrations of the «microlens arrays» formed by the optical standing waves tend to destroy the high-order Talbot images. In this contribution we present a solution to this problem and further discuss the feasibility of the focusing-Talbot approach.

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9. **Poster session on "Atomic interferometry" - Session de posters sur "L'interférométrie atomique".**

- Guiding and cooling of cold atoms in a dipole guide (**Laurence PRUVOST**)
- Diffraction and interference of the Bose-Einstein condensate by pulsed standing lignt waves (**Yuri OVCHINNIKOV**)
- Coherent channelling of atomic de Broglie waves (**Jorg SCHMIEDMAYER**)
- Atom lasers – Ultrabright sources of matter waves (**Immanuel BLOCH**)
- An improved Atom-Interferometer gravity gradiometer (**M.J. SCHNADEN**)
- A charged wire interferometer for atoms (**Tilman PFAU**)
- Controlling Kapiza-Dirac effect with interference (**A.M. ISHKHANYAN**)
- A cold atom gyroscope (**Jérôme FILS**)
- Searching for a possible time dependence of the fine structure constant : a proposal using cold atom fountains (**Sébastien BIZE**)
- Using the best geometry for a Mach-Zehnder atomic interferometer (**Caroline CHAMPENOIS**)

Guiding and cooling of cold atoms in a dipole guide

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Rubidium atoms, initially cooled and trapped in an optical molasses, have been efficiently guided on a large distance (0.3 m) by using the dipole force created by an vertical, intense (15 W) and focused far detuned Nd:YAG laser. About 40% of the atoms of the optical molasses have been guided. For a convergent laser beam, the dipole potential depth increasing, a compression of the cloud has been observed simultaneously to an increase of the transversal cloud temperature. We obtain an atomic flux increase of 3 orders of magnitude at the laser beam waist. For a divergent laser beam, we observe an adiabatic cooling, decreasing the transversal temperature from 9.5 to 2.5 μK. The experimental data are analysed with a Monte-Carlo approach coupled to the Simion 3D software for the trajectory calculation. Other beam configurations will be proposed.

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Diffraction and interference of the Bose-Einstein condensate by pulsed standing light waves

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We have studied experimentally and theoretically the diffractional splitting of a Bose-Einstein condensate (BEC) released from an adiabatically expanded magnetic trap by pulsed standing light waves. We observed that in a thick grating limit, when the interaction time of atoms with light is comparable or much larger than the characteristic vibrational period of atoms in a standing wave potential, the width of the momentum distribution of the diffracted atoms exhibits strong oscillations as a function of the pulse duration, corresponding to periodic focusing and collimation of the BEC inside the standing light wave.

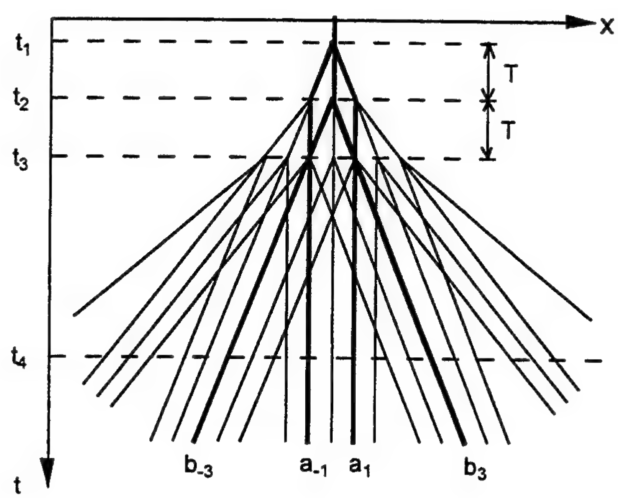

FIG. 1. Time domain three-grating interferometer.

The interference of the diffracted atoms in a three pulsed grating interferometer (fig.1) is demonstrated and the influence of the interaction between the atoms on the interference is discussed. Calculations of the atom interference in a multiple-beam interferometer are presented.

Coherent channelling of atomic de Broglie waves

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Transport of atoms becomes more and more important in atom optics, not only in interferometric experiments but also in order to store quantum states. Versatile, controlled coherent transport is essential for further progress in the field.

We studied experimentally the transport of atoms in strong light potentials, where the transversal energy of the atoms is lower than the height of the potential barriers. The atoms are confined between the planes of the standing light wave and channel in these „waveguides" through the crystal. Surprisingly the farfield pattern of diffraction at such a „channeling " crystal looks quite similar to the diffraction pattern of a thin grating. A lot of diffraction orders are populated quite insensitive to the incidence angle. That there is still interference after the long interaction time demonstrates that coherence is preserved during the guiding process.

If we compare our system of atoms in guides made of light with the classical system of balls in corrugated sheet iron, we also expect to see oscillations inside the channels (caustics) for different interaction times. We can demonstrate these oscillations in the envelope of the atomic diffraction pattern. For long interaction times these oscillations damp out and the width of the envelope is a constant only determined by the width given from the single channel. The centre of mass leaves the crystal in analogue to the classical picture in direction of the potential well independent of the incidence angle.

We have realised with our experiment a system where the transition of a wavelike behaviour as diffraction at a periodic potential to a particallike behaviour like balls in corrugated sheet iron can be studied. To understand this transition in detail is essential to understand the connection between quantum mechanics and the classical world.

This work was supported by the Austrian Science Foundation (FWF), project S065-04 and by the European Union, contract Nr TMRX-CT96-0002.

Atom Lasers – Ultrabright Sources of Matter Waves

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Four decades ago the first optical lasers were demonstrated, marking a scientific breakthrough: ultimate control over frequency, intensity and direction of optical waves had been achieved. With Bose-Einstein condensation in a dilute gas of atoms a similar level of control over matter waves has been attained [1]. Using an output coupling mechanism atoms can be extracted from the Bose-Einstein condensate in a controlled manner thereby creating a coherent atomic beam [2]. In my talk I will report on the first demonstration of an output coupler which continuously extracts atoms from a Bose-Einstein condensate of ^{87}Rb atoms. The atomic beam formed in this process has unprecedented properties: its brightness exceeds the brightness of the best sources for slow atoms by at least six orders of magnitude and the high degree of coherence of such *atom laser beams* [2,3,4,5] make them an ideal source for experiments in the novel field of coherent atom optics. I will outline possible applications of this novel source of matter waves, especially in the field of atom interferometry.

Continuous output coupling of atoms from a Bose-Einstein condensate, as done in our work, may furthermore act as a sensitive probe of local condensate properties and I will present our recent measurements on spatial coherence properties of BEC's at finite temperatures.

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An Improved Atom-Interferometer Gravity Gradiometer

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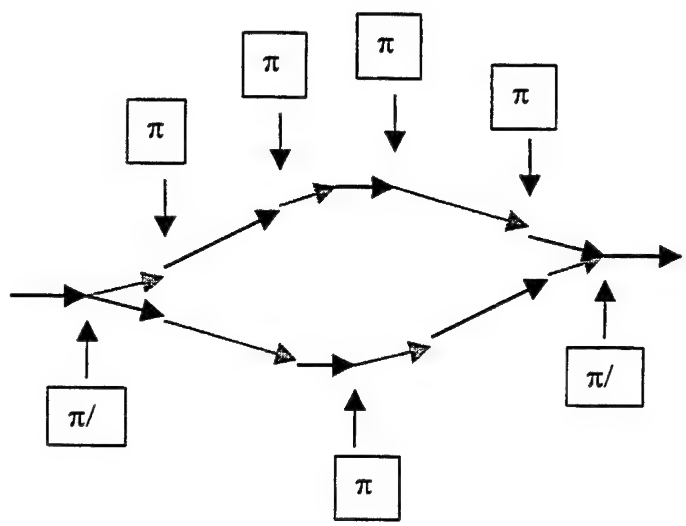
Measurement of the gradient of gravitational fields has important scientific and technical applications. These applications include measurements of G, the gravitational constant, tests of general relativity, covert navigation, underground structure detection, oil-well logging and geodesy. We have previously demonstrated [1] an atom-interferometer based gravity gradiometer that had sufficient sensitivity to measure the gradient of the Earth's gravitational field. At the Earth's surface this gradient has the value ~3×10^{-7} g / m. This device measured the relative acceleration of two ensembles of laser cooled cesium atoms that were separated by -1.3 m The relative acceleration of the atom clouds was measured by driving Doppler-sensitive stimulated two-photo Raman transitions [2] between the ground-state hyperfine levels. We used a $\pi/2 - \pi - \pi/2$ sequence of Raman pulses. The sensitivity of the gradiometer depends on the square of the interaction time. The atoms were captured and cooled in a pair of magneto-optical traps (MOTs). For our initial results, the MOTs were simply switched off and the atoms fell. This limited the interaction time in our experiment to 60 ms.

To improve the sensitivity of the gradiometer we have reconfigured it to launch both ensembles of atoms upwards on ballistic trajectories. This has increased the interaction time to 300 ms which has led to a direct increase of sensitivity of a factor of 25. The atoms travel 12 cm upwards during the fountain. This height is limited by the geometry of our vacuum chambers. To further increase our sensitivity we have investigated more complex interferometers that increase the separation between the two paths of the interferometer and thus increase sensitivity to inertial forces, The interferometer shown below uses extra n pulses to give an additional factor of 3 in sensitivity,



We have constructed an instrument that is already competitive with traditional gravity gradiometers in terms of sensitivity, while offering considerable benefits in terms of absolute calibration relative to cesium wavelengths and long term stability.

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Light force lithography in chromium

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In atom lithography, neutral atoms are focused by laser light to form a periodic pattern on a substrate. We have realized a varitety of two-dimensional structures of chromium on a silicon substrate by employing a polarization gradient light mask with uniform intensity [1] as well as intensity gradient. The generated structures exhibit periods below 100nm. The results are explained by a theoretical model which takes into account the magnetic substructure of the atomic transition employed and the influence of a static magnetic field. Future atomlithography experiments will make use of the selectivity of the atom light interaction. By structuring a dopand in a homogeneously growing matrix a material can be fabricated that provides a change of its optical properties on the scale of the optical wavelength. This may find applications in the field of photonic crystals.

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CONTROLLING KAPITZA-DIRAC EFFECT WITH INTERFERENCE

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The quantum-mechanical theory [1] of the coherent scattering of atoms in the field of standing light wave predicts a symmetric diffraction pattern of distribution by momenta. However, the experiments [2] on the scattering of thermal neutral atoms of sodium by a strong field of two counterpropagating light pulses have displayed unexpected anomalies: the momentum distribution was found to be an asymmetric one, and the dependence of the scattering amplitude (at the fixed angle of observation) has an oscillatory character. The period of oscillations is not a function of the field intensity or observation angle; it is determined by the distance between the atomic beam and the reflecting mirror (the standing wave was generated by reflecting a pulse of light from a mirror) [2].

Since during the round-trip of the leading edge of the pulse from the atomic beam to the mirror and back, the atoms see a traveling wave only the traveling wave prepares the atoms so that they do not enter in the ground sate, but rather in a superposition of ground and excited states. This preparation ought to give rise to the asymmetry. Anomalous scattering of this origin is analyzed in detail in [3]. It was shown that for certain types of mixed initial states (for which the ground and exited levels differ by one photon momentum) the diffraction of atoms indeed occurs asymmetrically. It was shown that the oscillations of the asymmetry value of the scattering diagram (depending on the distance from the reflecting mirror) as well as the oscillatory character of the frequency dependence of scattering amplitude and other peculiarities observed in the experiment [2] are again caused by the preliminary excitation of atoms by the incident running wave.

The key to the anomalous scattering is quantum mechanical interference. In the case considered until now, the interference is between ground state atoms and excited atoms whose momenta differ by one photon momentum. In the present work we consider more general type of preparation prior to standing-way diffraction that has so far been treated neither experimentally nor theoretically.

First, we consider the peculiarities of the anomalous scattering of an effective two-level system using initial conditions of the form: $a_1(0)=(1-e^{2ikz})/\sqrt{6}$, $a_2(0)=0$ that can be realized, for instance, using an optical transition $j_g=1$ $j_e=0$ in a two-level atomic system with magnetic sublevels. Due to linearity of quantum mechanics, it may be seen immediately that after the standing-wave diffraction the ground and excited states' amplitudes read:

$$a_{1,2}(p,t)=\sum_{-\infty}^{+\infty}\frac{i^n}{\sqrt{2}}\left[\frac{\pm 1+(-1)^n}{2}\right]\left[J_n(2U_0t)+J_{n-2}(2U_0t)\right]\delta(p-p_0-n\eta k).$$

By virtue of the recursion relation for Bessel functions: $J_n(u)+J_{n-2}(u)=2(n+1)J_n(u)/u$, it is easy to see that the probability for the atom to get the momentum $n\eta k$ is given by: $P(n,t)=[(n-1)/(2U_0t)]^2 J_n^2(2U_0t)$.

This expression differs from the usual distribution $P(n)=J_{n-1}^2$ [1] by the factor $\sim n^2/(2U_0t)^2$. Since the Bessel functions tend to peak where the order equals the argument this factor exacerbates the emphasis on diffraction orders $n\approx 2U_0t$. Thus the considered initial state leads to narrowing of the wings of the momentum distribution.

Suppose next that the initial conditions are $a_1(0)=(-e^{2ikz}+2-e^{2ikz})/\sqrt{6}$, $a_2(0)=0$. Then an argument similar to the one above gives: $P(n,t)\approx(n/(2U_0t))^4 J_n^2$, that further emphasizes the wings of the standing-wave diffraction pattern: now the peaks are perceptibly narrower than in the previous case. By induction, it is not difficult to construct an initial state leading to the distribution $P(n,t)\approx(n/(2U_0t))^{2m} J_n^2$. Consequently, a superposition of mentioned specific initial states will result in a final distribution of the form

$$P(n,t)\approx\sum_m\frac{\alpha_{2m}}{(2m)!}\left(\frac{n}{2U_0t}\right)^{2m}J_n^2(2U_0t)=f_n(2U_0t)J_n^2(2U_0t)$$

with an arbitrary, in some sense, even function $f_n(2U_0t)$.

In summary, we have demonstrated that, with benign preparation of the atoms preceding standing-way diffraction, one may alter the diffraction pattern quite dramatically. The same applies if the auxiliary manipulations are performed *after* the standing-wave diffraction. The crux is to make use of quantum interference between the diffraction orders. Our observations beg the question as to how tightly one may control the diffraction. In the most general case one

considers arbitrary time dependences of the Rabi frequencies of the counterpropagating light waves. We know that in this way one might in principle alter the diffraction pattern profoundly. For instance, by subjecting the atoms to a sequence of counterpropagating π pulses, all atoms may be transferred into any desired diffraction order. Our hope is that, by using methods based on quantum interference, a similar steering of atomic beams could be achieved more gently and in a manner that is experimentally more robust.

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The Cold Atom Gyroscope (CAG) Project began at the LHA two years ago, and will be continued at the LPTF. The goal of this project is to develop a gyroscope based on the Sagnac effect for matter waves. The configuration of this interferometer is an equivalent of the optical Mach-Zehnder one. The atomic cesium beams arc split, redirected and recombined with a $\pi/2$ - π - $\pi/2$ sequence of stimulated Raman transitions. The first atomic interferometry experiments showing the Sagnac effect were set up by Ch. Bordé at the PTB in Braunschweig in 1991. The Sagnac sensitivity of such a device has also been demonstrated by P. Bouyer (IOTA) in a thermal beam experiment in M. Kasevich's group at Yale university. The sensitivity already approches the best laser gyroscopes. The CAG project will use cold Cesium atoms instead of a beam, which allows for a much smaller device, fitting in a 5Ox5Ox5O cm, and an improved sensitivity, about 10^{-5} deg/$\sqrt{}$hr. The improved portability of our system will allow for embarked experiments or ultra-high sensitivity Og set-up.

In Yale's gyroscope, a different pair of beams produces each Raman pulse and the device is not immune to optical phase fluctuations between the three pulses. This is a major limit for long-term stability. The CAG will use temporal Raman pulses, as in Stanford's atomic gravimeter, with one large pair of Raman beams. This will minimize the relative phase fluctuations between the three pulses. Additional reduction of optical phase sensitivity will be obtained by comparing the rotation mesurements of two counter-propagating atomic clouds. This operating mode will provide good long-term stabilité and allow for very long integration time. Moreover, it will provide additional information to extract spurious acceterations from the ineasured rotation signal.
The first CAG signal is expected before the end of this year. A theoretical study is in progress at the LHA in collaboration with Ch. Bordé to have a metrological description, and to determine all the systematic effects on the long-term sensitivity.

The CAG is well suited for operating in space. A Og CAG will allow foi reduced atomic velocity and consequently for longer interrogation time. As for PHARAO, this will improve by orders of magnitude the sensitivity. Furthermore, our parabolic design, limited by the falling effect on atoms due to gravitation, could be greatly simplified and reduced in size. It would bc well suited for tests of relativistic effects such as the Lense & Thirring one.

The following laboratories collaborates on this project:

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SEARCHING FOR A POSSIBLE TIME DEPENDENCE OF THE FINE STRUCTURE CONSTANT : A PROPOSAL USING COLD ATOM FOUNTAINS

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Interest in the search for a possible drift of the fundamental constants has been renewed by recent theoretical developments and cosmological observations. In its attempt to unify gravitation theory and quantum mechanics, string theory abandons Einstein's purely geometrical description of gravitational interaction. As a consequence, the equivalence principle is violated, which means that in freely falling frames, the outcome of any local non-gravitational experiment depends on where and when it is performed [1]. In the frame of this theory, α is thus expected to depend on space-time coordinates. Cosmological tests place a stringent limit to the temporal variation of α integrated over long time scales (~10^9 years): $\dot{\alpha}/\alpha \leq 5\times10^{-17}$ yr^{-1} (Oklo test [2]). On the other hand, as pointed out by [3], comparisons between ultra-stable frequency standards provide repeatable high precision laboratory tests on possible α variations.

We propose to use the high accuracy of LPTF's Cs and Rb cold atom fountains [4,5] to improve the previous clock results by a factor 100, i.e. search for a drift of α at a level of 10^{-16} per year. In this poster, we present recent results on cold atom fountains : measurement of the collisional frequency shift in Rb, rejection of the local oscillator phase noise in the comparaison between Rb and Cs fountains. We describe a dual fountain, which will operate with both Rb and Cs atoms simultaneously. Some of the effects altering the comparison between the two hyperfine frequencies could hence be rejected : phase noise of the local oscillator, room temperature and magnetic field fluctuations... Additional comparisons with Hg^+ ion frequency standards would provide a clear signature of α variation, if any.

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USING THE BEST GEOMETRY FOR A MACH-ZEHNDER ATOMIC INTERFEROMETER

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Atomic interferometry is a new and rapidly developing field (for a recent review, see [1]). Different devices can lead to atomic interferences but here we are concerned with a case where the interfering paths correspond to the same internal atomic state but to different trajectories. This type of experiments remains quite difficult because, if we except the case of cold atoms, the de Broglie wavelengths associated to atoms is very small.

Few interferometers of this kind have been already built, but here, we focus on devices using a design proposed by Clauser [2] and being similar to a Mach-Zehnder optical interferometef. In the atomic interferometers,the mirrors and the beam splitters are diffraction gratings which can be amplitude gratings, like in Pritchard's group [3], or phase gratings like in Zeilinger's group [4] or in Siu Au Lee's group [5]. These phase gratings are laser standing waves, quasi-resonant with an atomic transition and the diffraction can be explained by the Kapitza-Dirac effect. They can be thin or thick and the diffraction process do not give the same amplitudes depending of this thickness.

In our case, we choosed to use an atomic beam of Lithium, diffracted by phase gratings. Our experimental setup allows us to use thin as well as thick laser waves to diffract the atoms. We want to have a sufficiently wide spatial separation between the two interfering paths, to be able to let only one path interact with external perturbations (gas cell, electric field). So we decided to use a geometry very similar to the one of the interferometer built by Pritchard's group in MIT and to separate the gratings by the same distance (see figure 1). Other geometric parameters had to be adjusted when building the interferometer, the main ones being the width of the collimating slits and the distance between the last grating and the detector (in case of thin laser wave).

Thanks to analytic calculations and numerical simulations, we have estimated the contrast of the signal for different geometries and choosed the best one. All the results of this study can be found in [6]. They show that the geometry of an interferometer must be adapted to the type of diffraction used to separate the beam. For example, the detection geometry used by Pritchard's group is adapted to amplitude gratings but cannot be used in our case. More precisely, when using amplitude gratings, the fringe pattern can be viewed as a Moiré filtering by the grating G_3 of an atomic standing wave produced by the two paths interfering

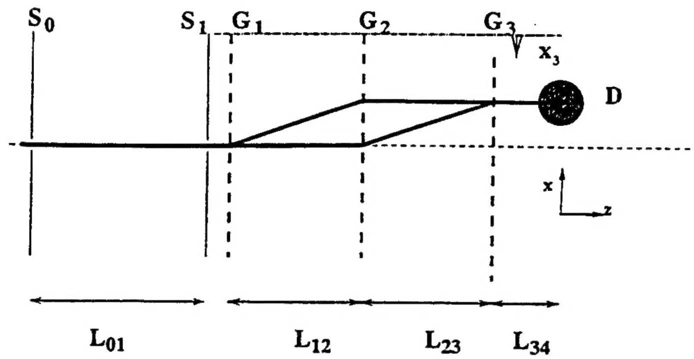

Figure 1: Schematic drawing of an atomic interferometer of the Mach-Zehnder type. G_1, G_2 and G_3 are the three gratings and D designates the atomic detector. S_0 and S_1 are collimating slits, used to reduce the transverse dispersion of the beam. $L_{01} = 0.8$m, $L_{12} = L_{23} = 0.6$m et $L_{34} \simeq 0.4$m.

in the plane of G_3. When using phase gratings, the Moiré filtering effect disappears and the interference signal appears only when the various beams produced by diffraction by G_3 separate. The contrast increases rapidly when the distance L_{34} from G_3 to the detector increases and the calculated contrast can reach a rather large value ($\geq 90\%$) even in the unfavorable case where the stray beams from other paths are included in the calculation.

The first experimental step is to study the diffraction of an atomic wave by a laser standing wave, near resonant with a transition of Lithium. Different behaviours should be observed, depending on the thickness of this laser wave, its detuning and its power. We hope to present preliminary results at the conference.

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